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HORIZONTAL CONVERGENCE AND THE OCCURRENCE OF SUMMER PRECIPITATION AT MIAMI, FLORIDA

STANLEY DAY

Weather Bureau Airport Station, Miami, Fla.

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ABSTRACT

The Bellamy nomograph is applied to a triangle over southeastern Florida and adjacent waters to compute the horizontal divergence and convergence in the lower levels for the period June–August 1951. The general diurnal pattern and the extent of the sea-breeze effect are established and graphed, as are the variations in the pattern between wet and dry days. A comparison is made between the results of this study and those obtained from a similar investigation in central Florida. The relationship between the partial and total convergence values and the occurrence of precipitation is examined. The short test period and lack of data prevent any determination of valid forecast rules but a study of the charted data reveals several promising leads meriting further investigation.

INTRODUCTION

Summer showers and thunderstorms of apparent local origin but of severe intensity and with excessive precipitation are a major forecasting problem in Florida, particularly in the southeastern coastal area around Miami. These showers, occurring within a generally uniform unstable mT air mass, are not typically related in time or intensity to the passage of fronts, squall lines, easterly waves of noticeable magnitude, or hurricanes. The purpose of this study is to determine the relationship between horizontal convergence over southeastern Florida as measured by the Bellamy nomograph and the occurrence of summer precipitation.

Examination of previous investigations of the Florida shower problem indicates that theories as to the causes of the development of the large areas of horizontal convergence necessary to widespread thunderstorm activity over Florida cannot be completely reconciled. Riehl [1] ascribes the cause to the presence of a more or less permanent zone of horizontal convergence across the Florida peninsula as a result of a permanent trough of low pressure at some level in the atmosphere. Byers and Rodebush [2] have investigated the Florida thunderstorm as it occurs over the central portion of the State by using the Bellamy nomograph [3]. In their report it is stated that easterly waves, hurricanes, and frontal zones were found to be too rare to account for the almost daily thunderstorm

activity in the portion of the State that they were considering. They concluded that the shower activity was set off by a low level mechanism, the conflicting sea breezes of the east and west Florida coasts, meeting over the center of the peninsula. To support this theory graphs of monthly convergence patterns were developed showing the time of maximum occurrence of convergence coinciding with the time of maximum shower occurrence.

The triangle chosen by Byers and Rodebush for the central Florida study, with Jacksonville, Miami, and Tampa at the vertices, was of extensive length with these vertices subject to different maritime exposures. The centroid of this triangle falls somewhere south of Orlando near the location of the Thunderstorm Project of 1946, which provided the basic data. The triangle was chosen deliberately to measure the conflicting sea-breeze effect since it was felt that this was the mechanism that makes possible the daily afternoon thunderstorms over the interior of Florida. The sea breezes establish an organized convergence zone over the peninsula on days when no large scale synoptic disturbance is present, the result of diurnal heating which may be considered as an indirect cause of the inland thunderstorm activity. However, without the converging effect of the double sea breeze over the Florida peninsula, the diurnal heating alone would not produce this activity.

This theory explains the mechanisms in operation over

the central portion of the State but cannot be applied directly to the southeastern coastal area. To understand the shower problem peculiar to Miami and southeastern Florida, and how it differs from the rest of the peninsula, it is necessary to consider the geographical factors involved. Miami is located at the extreme southeastern end of a long, nearly flat peninsula thrust deep into the influence of the trade winds, and into the warm waters of the Gulf Stream. Less than 60 miles to the west are the cooler waters of the Gulf of Mexico. Winds of any direction other than northwest have had at least some recent water trajectory. The prevailing winds over south Florida have easterly or southerly components throughout the summer. As a result the air reaching the peninsula has a water history of extended duration, and is always identifiable as maritime tropical, with slight variation either in dew points in the lower levels or in the lapse rate. Yet with these apparently constant factors, the daily precipitation patterns on the southeastern coast are anything but constant.

Miami and the lower east coast do not experience as many afternoon thunderstorms as the central part of the State, but do have more thunderstorms occurring during the night and morning [4]. Also there are periods of as much as several days in which the lower east coast experiences little or no rain while the precipitation pattern goes on unchanged in the central portions. This would suggest a modification in the cause of the showers as set forth by Byers and Rodebush. It is undoubtedly some combination of the mechanism of the sea breeze and the influence of traveling synoptic features as described by Riehl. Gentry and Moore [5] have investigated the variation of the interaction of the sea breeze and gradient wind flow, the timing of the onset of the sea breeze, and have correlated these factors with the time of shower occurrence in the summer at places within 25 miles of the southeast Florida coast.

COMPUTATION OF CONVERGENCE

After the appearance of Bellamy's article [3], a study similar to the one conducted by Byers and Rodebush was set up for the Miami area. Through the fortunate location of pilot balloon stations at Melbourne, Fla. (since replaced by Patrick Air Force Base, Cocoa, Fla.), Nassau, Grand Bahamas, and Key West, Fla., it was possible to set up a nearly equilateral triangle with Miami very near the centroid. (See fig. 1.) Assuming an exact equilateral relationship between the stations facilitated the construction of a table of partial divergence values for each station. Computations were so adjusted that the partial divergence values represent the percentage of volume of air removed or added in a 3-hour period. A sample column of the table is shown in figure 2. Positive values represent divergence, negative values convergence.

Beginning at 0300 GMT, June 1, 1951, and at each 6-hourly pibal observation thereafter, a record was kept of the partial divergence values for each station of the

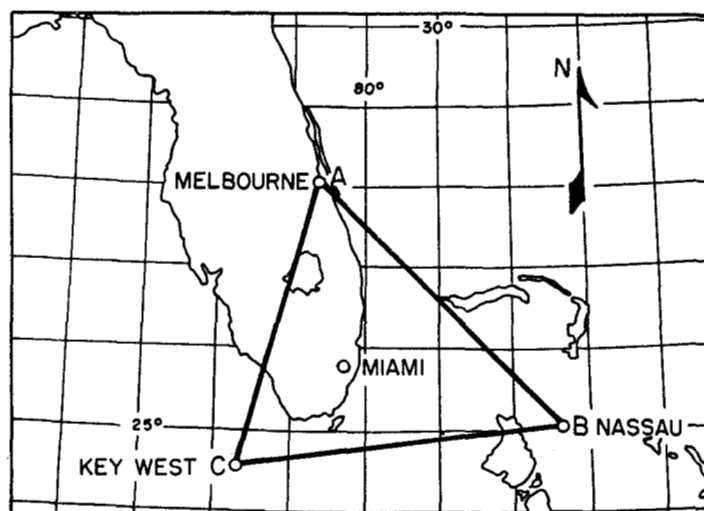


FIGURE 1.—Map of South Florida and adjacent waters showing triangle ABC formed by the pilot balloon stations used in computing convergence at Miami.

30°			
KTS	A	B	C
5	-05	-02	+07
10	-10	-04	+15
15	-16	-06	+22
20	-21	-08	+29
25	-26	-10	+36
30	-31	-13	+44
35	-36	-15	+51
40	-42	-17	+59

FIGURE 2.—Sample column of the computed table of divergence (+) and convergence (−) values in units of (3 hr).⁻¹ Partial values at stations A, B, and C (see fig. 1) are shown for a 30° wind direction and for the wind speeds (knots) given in the stub.

Date	<u>7-1-51</u>			Winds Aloft Time	<u>1500 GMT</u>			Raob Time	<u>1500 GMT</u>		
Winds Aloft:				Computations:							
Hgt.	A	B	C	Hgt.	A	B	C	Total			
Sfc.	<u>2406</u>	<u>1315</u>	<u>1508</u>	Sfc.	<u>+02</u>	<u>-20</u>	<u>-03</u>	<u>-21</u>			
1000	<u>2508</u>	<u>1415</u>	<u>1506</u>	1000	<u>+02</u>	<u>-19</u>	<u>-02</u>	<u>-19</u>			
2000	<u>2510</u>	<u>1414</u>	<u>1606</u>	2000	<u>+02</u>	<u>-18</u>	<u>-04</u>	<u>-20</u>			
3000	<u>2513</u>	<u>1414</u>	<u>1605</u>	3000	<u>+02</u>	<u>-18</u>	<u>-03</u>	<u>-19</u>			
4000	<u>2311</u>	<u>1514</u>	<u>1803</u>	4000	<u>+08</u>	<u>-15</u>	<u>-04</u>	<u>-11</u>			
5000	<u>2310</u>	<u>1513</u>	<u>1803</u>	5000	<u>+07</u>	<u>-13</u>	<u>-04</u>	<u>-10</u>			
Precipitation:											
Miami WBAS		6 hr <u>1830 GMT to 0030 GMT</u>			<u>.15</u>	12 hr <u>0030 GMT to 0630 GMT</u>		<u>0</u>			
Miami WBO		" "			<u>.59</u>	" "		<u>0</u>			

FIGURE 3.—Sample worksheet on which pibal data and convergence computations for stations A, B, and C were recorded every 6 hours.

triangle, with the algebraic summations assumed to be the net effect upon the centroid, Miami. Due to the inconsistencies of the pibal observations in reaching

heights above 5,000 feet, this study was limited to data compiled below that height. Also tabulated were the precipitation records from both the Miami Weather Bureau Airport Station and the Miami City Office. This record was concluded with the 2100 GMT observation, August 31, 1951. A sample data sheet is shown in figure 3.

AVERAGE DIURNAL VARIATION OF CONVERGENCE

The daily convergence patterns for each month and the average convergence for the entire period were computed and graphed as shown in figure 4. These curves show a diurnal fluctuation of convergence that varies from month to month in intensity, yet they are fairly consistent in general pattern and average out over a longer period into a symmetrical curve. The variation of daily oscillations can be related to the daylight and darkness periods, and thus may reflect the land-sea relationship. The 0300 GMT readings indicate strong divergence, while this is

completely reversed by the daytime circulation pattern at 1500 GMT. At 2100 GMT the figures average out to produce a neutral effect, all levels falling on or near the zero line. In the July and August charts the symmetry of the curves becomes more pronounced with the convergence peak falling decisively at 1500 GMT, and the levels arranging themselves in order, with a minimum of convergence and even divergence appearing around 4,000 to 5,000 feet, representing a "spill-over" of the rising column of air. In August this is especially well marked.

The 3-month averages produce a symmetrical pattern with the levels arranging themselves in almost exact order at the 0300 GMT and 1500 GMT observations, and passing through a "node" or neutral stage at both the 0900 GMT and 2100 GMT observations. The monthly curves become more orderly in their behavior as summer advances, approaching the average curve. This can be best explained by considering that in June the air mass distribution of the lower peninsula is not completely maritime

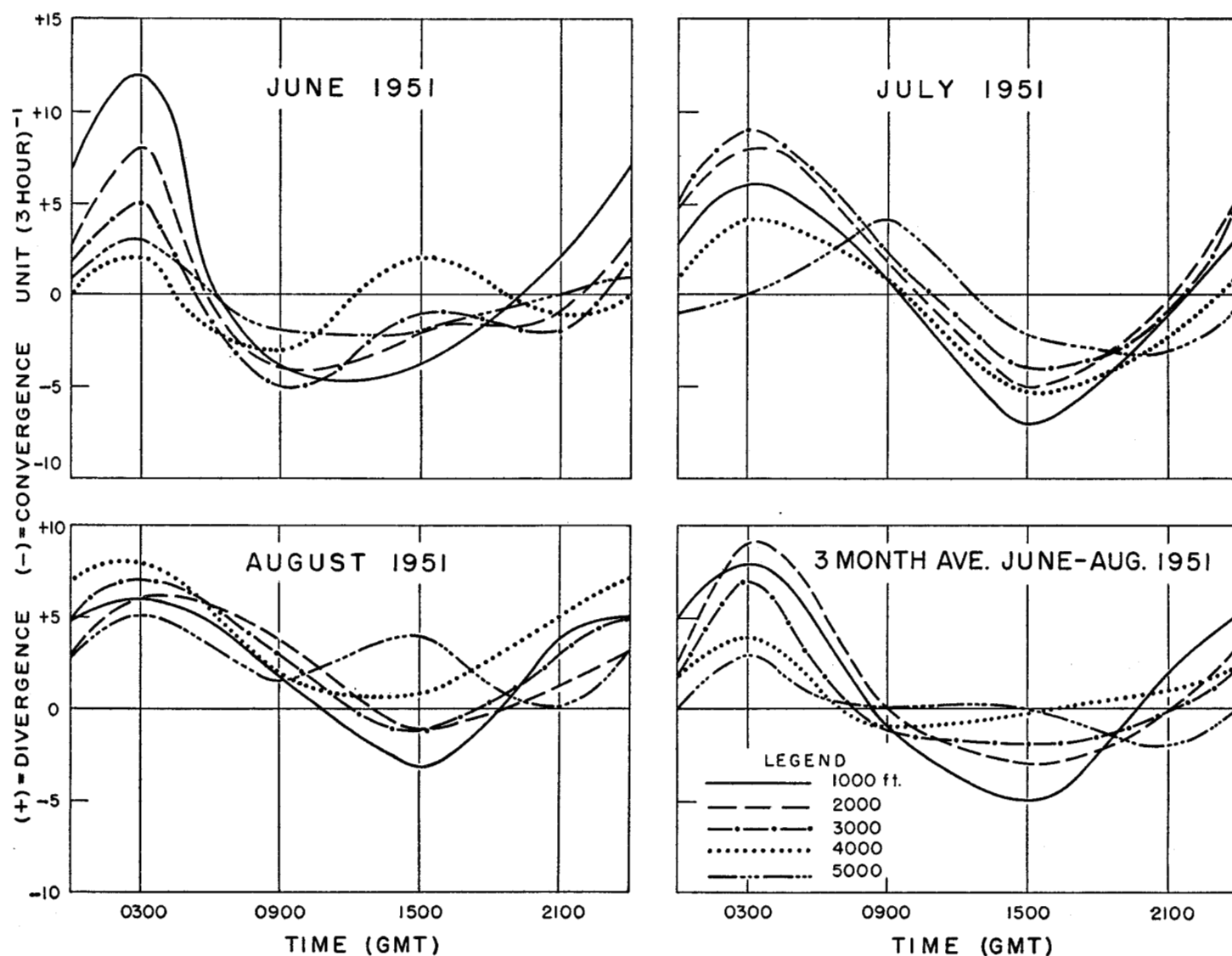


FIGURE 4.—The average diurnal variation in divergence and convergence at Miami, Fla., for levels 1,000 feet through 5,000 feet for June, July, and August 1951, and for the 3-month season.

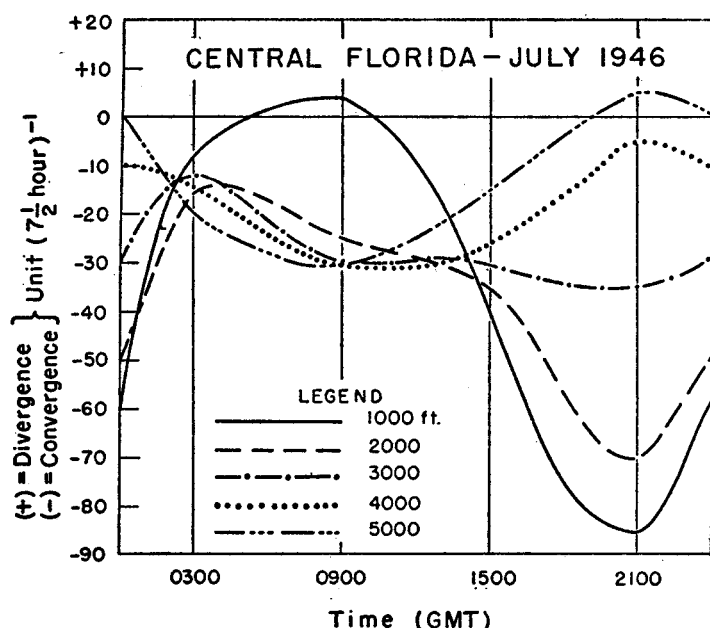


FIGURE 5.—Diurnal variation of divergence and convergence in lowest 5,000 feet for July 1946 over the central Florida peninsula (adapted from Byers and Rodebush [2]). This set of curves closely resembles the average for the test period May 1–September 15, 1946, and is selected as being representative of the entire study [2]. Note the exact arrangement of levels at 2100 GMT. The results in this figure should be multiplied by 0.4 for conversion to the units used in the present study.

tropical in nature, but instead is still subject to weak incursions of northern air which distorts the circulation pattern for sufficient time to put the averages out of balance.

The curves thus developed are in general agreement with those at Orlando so far as symmetry and configuration are concerned. In the example shown of the central Florida curves (fig. 5) note that the convergence exceeds the divergence over a 24-hour period and the net result is a slowly rising air mass. The “nodes” fall below the zero line, and the afternoon convergence peak falls to a figure in excess of the summation of the other observations. In contrast, in the south Florida curves the diurnal swing is nearly balanced with equal amounts of divergence appearing at 12-hour intervals, without an excessive amount accumulated at any one period, and with the final summation being slightly divergent.

These differences can be shown to relate to the exposures of the two triangles. One is composed entirely of the peninsular land mass, yet the values of convergence are determined by wind action at the vertices, all with varying water exposures. The convergent values thus may often represent a conflict between three different types of maritime influence. In contrast, the triangle set up for the Miami investigation is composed of more than half water surface, with the stations much closer together, and may be considered as being in one homogeneous air mass the great majority of the time. Two of the stations are completely maritime in exposure. All three stations are on the same side of the peninsula in relation to the large scale easterly flow, and the variations in the types of sea

breeze at the separate vertices can be considered to be minimized.

CONVERGENCE AND PRECIPITATION RELATIONS

In order to determine the changes in the convergence pattern that relate to changes in the precipitation pattern, the data were broken down into two sets, corresponding to rain and no-rain days, and replotted. Wet days were considered to be those on which a trace or more of rain was recorded at either the Miami Airport Station or City Office within 12 hours following the time of the wind observations. A dry day was one on which no rain was measured at either station during the same period.

In figure 6 the wet-day and dry-day convergence curves for the separate months and the 3-month average are shown for the lower 3,000 feet. Note that the wet-day curves in most instances appear to be exaggerations of the normal curves, with an excess of convergence during the daytime observations. The June curves show that wet-day values distort the curve at the “node” periods at 2,000 feet and above, so that a departure toward convergence at 0900 GMT and 2100 GMT becomes especially significant. Another point to notice in the June curves is that more divergence at the 0300 GMT period is the forerunner of rain. This may be attributed to night-time and early morning showers in the subsequent 12-hour period that occur at high levels, with divergence occurring below in the charted levels. It also may be that such divergence occurs before the advance of the sea breeze front at Miami which often bears onshore light early morning showers. In July the greatest differences between the wet-day and dry-day curves occur at 0300 GMT and 1500 GMT with the greatest departure at 1500 GMT and the entire wet-day curve more convergent. In August the two curves are much more closely related in their configuration and do not lend themselves to an easy explanation of the variations. Further data may develop a more clear cut pattern of variation such as evidenced in the June and July curves.

Despite the establishment of such strong diurnal patterns through the use of averages, it must be remembered that the 6-hour consecutive values from the actual data record do not follow the swings from strong plus to strong minus each day during a wet or dry period but rather become part of a larger scale pattern of sustained convergence or divergence extending over as much as a 5- to 7-day cycle. These cycles can best be measured by subtracting the average values from the actual observed values for corresponding times and heights. The algebraic remainder represents the influence of some change in the overall synoptic picture that has distorted the normal pattern. Abrupt changes in value are important in that large convergence departures from the general trend of the observed curve were noted to precede rain of considerable intensity or an extended period of shower activ-

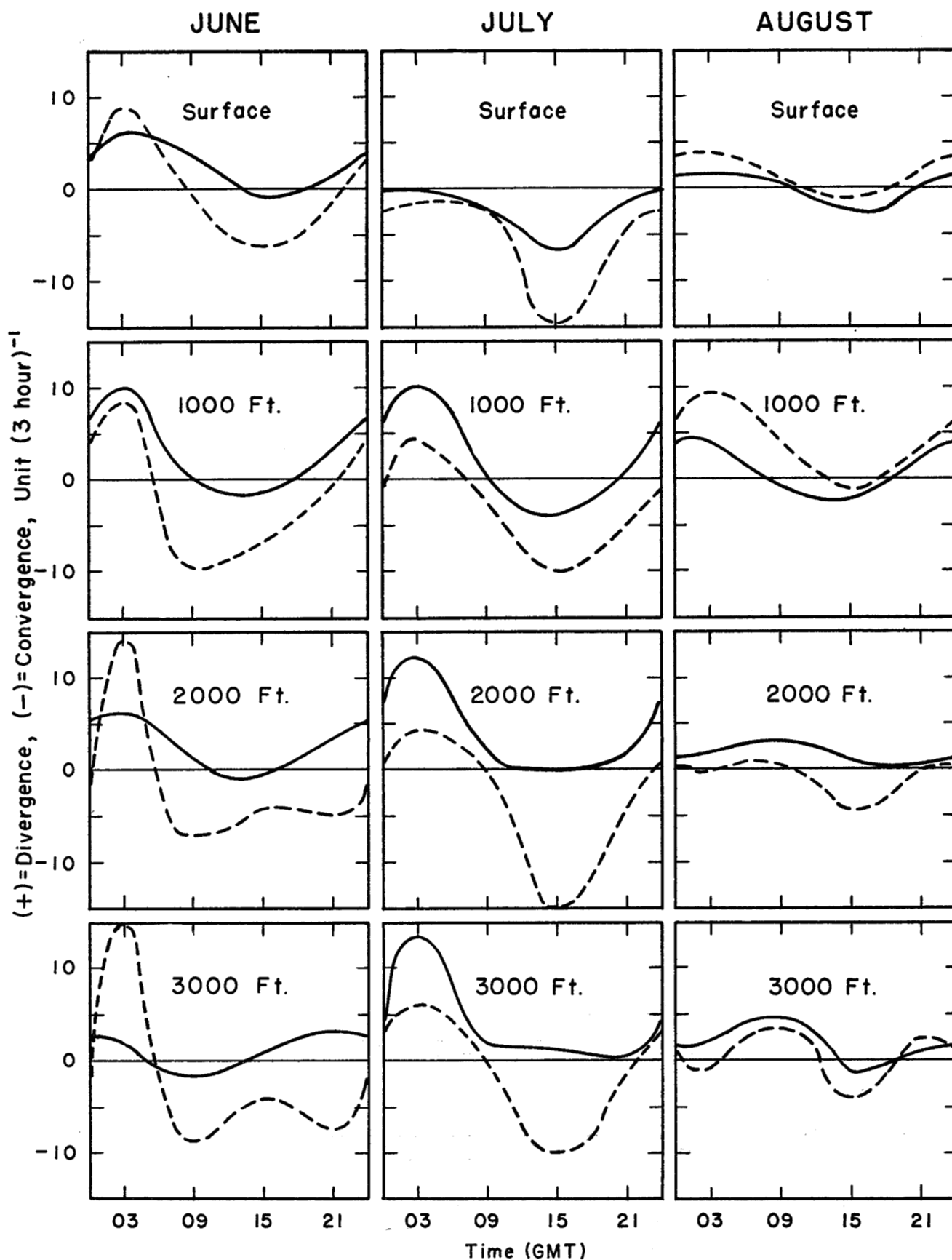


FIGURE 6.—The average diurnal variation of divergence and convergence for wet days (dashed line) and dry days (solid line) at Miami, Fla., by altitude and by months. Wet day means trace or more of rain at either WBO or WBAS, Miami; dry day means no rain at either measuring station.

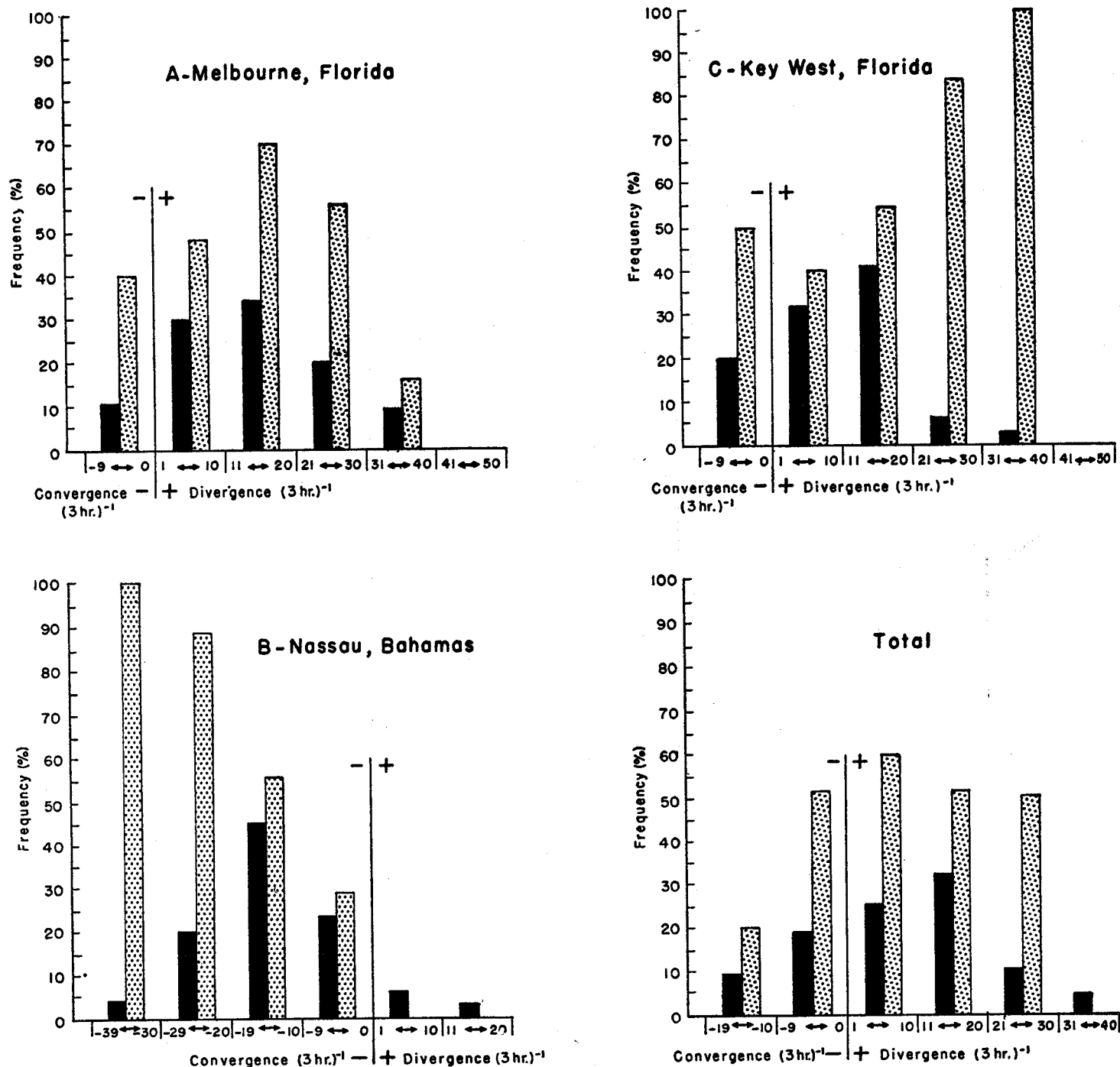


FIGURE 7.—Percentage of occurrence of divergence and convergence by classes of ten units (black bars) for each station (partial values) and for total values; and percentage of occurrence of each class followed by rain within 12 hours (stippled bars). Based on 1,000-foot data, 0300 GMT observation, for the entire 3-month test period.

ity. Conversely, sudden divergence departures from the curve have indicated the advent of a dry period. Unfortunately, the lack of data prevents the development of any definite rules along this line.

PARTIAL CONVERGENCE AND PRECIPITATION RELATIONS

The next step was to determine to what extent the partial values of each of the vertices influence the total, and if possible how the influence could be related to the pre-

cipitation record. It was found that Nassau, being directly upwind from Miami in most of the observations, was naturally the most influential in determining the total amount of convergence. Melbourne, having the most variable wind pattern, affected the divergence and convergence totals in nearly equal amounts. Key West, being farther removed from the wind pattern that affects the east coast, contributed the least to the variations of convergence, but was the most responsible for the occurrence of large divergence readings.

To relate this information to the precipitation required the construction of a table showing the percentage of wet-day occurrence as related to the partial values at each station. A section of this table is graphed in figure 7. The example shown contains the data derived from the 1,000-foot values of convergence at the 0300 GMT observation period averaged for the entire test period. Similar graphs can be drawn for the other levels and observation times. The black bar-graph represents the percentage frequency of each partial value of convergence and divergence at the three vertices, "A", "B", and "C", corresponding to Melbourne, Nassau, and Key West, respectively. The percentage frequency of the summation of the partials is shown by the black bars on the "Total" graph. Note that this portion of the graph is very similar to the normal distribution curve, and if sufficient data were introduced into the study the normal distribution would likely be approached.

The stippled bar-graph represents the percentage frequency of the partial and total values that were followed by rain within 12 hours. The "B" and "C" curves are most significant when examined in this respect. On the "B" graph, although the frequency of strong partial convergence values falls off rapidly toward the left, the frequency of strong convergence values that were followed by rain increases rapidly in the same direction. For example, while values -10 to -19 (3 hr.)⁻¹ occur 45 percent of the time, they result in rain within 12 hours 56 percent of the time. The occurrence of -20 to -29 (3 hr.)⁻¹ is but 20 percent of the total, but almost 90 percent of these readings precede rain within 12 hours, and -30 to -39 (3 hr.)⁻¹ while occurring but 4 percent of the time are always followed by rain within 12 hours for a reading of 100 percent. The data on the divergence side of the "B" graph are very limited but suggest a no-rain situation.

However, the "C" graph shows increasing likelihood of rain as the divergence values increase. The relationship of this rather unexpected factor to the resultant rain is best found in an examination of the wind shifts around an easterly wave. With such a wave near or over Miami, Nassau (or "B") being to the east of the wave, has a southeast or convergent wind with relation to the triangle. Key West, or "C", has a divergent northeast wind west of the trough. Melbourne, or "A", shows no variation other than that expected by use of the normal curve. The two portions of the bar-graph show similar tendencies throughout, and the same is true of the "Total" graphs.

Similar graphs for the other levels and observational periods show that the relationship of the partials and the total to the precipitation varies with the time of day. The totals are most important in relation to precipitation in the 1500 GMT data, while the partials are not clearly related. At 0900 GMT and 2100 GMT little can be derived from either the partials or the total as they relate

to the likelihood of rain. This further supports the theory of the "node" at those times at which no indicative differences can be detected at any level or station and the air circulation throughout the triangle is in a state of confused transition.

From a complete set of graphs similar to those in figure 7 it should be possible to formulate some type of probability forecast of rain occurrence. This, when combined with other parameters, may prove to be the key to the development of a measurement method critical enough to detect the passage of minor disturbances over Miami, and thus provide another tool for the job of solving the troublesome problem of summer precipitation at that station.

CONCLUSION

The original objective of this study was to formulate some clear-cut forecasting rules by correlating the divergence values with the precipitation record. Analysis of the results indicates that the data are much too sparse to permit any such definition of rules. However, there is sufficient evidence to indicate the general value of the study, and the use of computed divergence and convergence values as a forecasting tool merits further investigation.

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